lowable bandwidth compared with BPC, resulting in a factor of two increase in the range resolution of the radar. The MSK waveform also has been demonstrated to have an ambiguity sidelobe structure very similar to BPC, where the sidelobe levels can be decreased by increasing the length of the m-sequence used in its generation.

This ability to set the peak sidelobe level is advantageous as it allows the system to be configured to a variety of targets, including those with a larger dynamic range. Other conventionally used waveforms that possess an even greater spectral efficiency than the MSK waveform, such as linear frequency modulation (LFM) and Costas frequency hopping, have a fixed peak sidelobe level that is therefore not configurable, and can be exceeded by high contrast targets. Furthermore, in the case of a multistatic experiment observing a target in motion, self-interference from the transmitter to the receiver is mitigated by the MSK waveform. Waveforms that have delay Doppler coupling, such as LFM, provide no such protection.

This work was done by Kevin J. Quirk and Meera Srinivasan of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-48367

Telescope Alignment From Sparsely Sampled Wavefront Measurements Over Pupil Subapertures

NASA's Jet Propulsion Laboratory, Pasadena, California

Alignment of two-element telescopes is a classic problem. During recent integration and test of the Space Interferometry Mission's (SIM's) Astrometric Beam Combiner (ABC), the innovators were faced with aligning two such telescope subsystems in the presence of a further complication: only two small subapertures in each telescope's pupil were accessible for measuring the wavefront with a Fizeau interferometer.

This meant that the familiar aberrations that might be interpreted to infer system misalignments could be viewed only over small sub-regions of the pupil, making them hard to recognize. Further, there was no contiguous surface of the pupil connecting these two subapertures, so relative phase piston information was lost; the underlying full-aperture aberrations therefore had an additional degree of ambiguity.

The solution presented here is to recognize that, in the absence of phase piston, the Zygo measurements primarily provide phase tilt in the subaperture windows of interest. Because these windows are small and situated far from the center of the (inaccessible) unobscured full aperture, any aberrations that are higher-order than tilt will be extremely high-order on the full aperture, and so not necessary or helpful to the alignment. Knowledge of the telescope's optical prescription allows straightforward evaluation of sensitivities (subap mode strength per unit full-aperture aberration), and these can be used in a predictive matrix approach to move with assurance to an aligned state.

The technique is novel in every operational way compared to the standard approach of alignment based on full-aperture aberrations or searching for best rms wavefront. This approach is closely grounded in the observable quantities most appropriate to the problem. It is also more intuitive than inverting full phase maps (or subaperture Zernike spectra) with a ray-tracing program, which must certainly work in principle, but in practice met with limited success. Even if such classical alignment techniques became practical, the techniques reported here form a reassuringly transparent and intuitive check on the course of the alignment with very little computational effort.

This work was done by Eric. E. Bloemhof, Xin An, Gary M. Kuan, Douglas M. Moore, Joseph F. O'Shay, Hong Tang, and Norman A. Page of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47814

Method to Remove Particulate Matter From Dusty Gases at Low Pressures

This method could be of use to the semiconductor industry to remove particles during low-pressure plasma processing.

John F. Kennedy Space Center, Florida

Future human exploration of Mars will rely on local Martian resources to reduce the mass, cost, and risk of space exploration launched from Earth. NASA's In Situ Resource Utilization (ISRU) Project seeks to produce mission consumables from local Martian resources, such as atmospheric gas. The Martian atmosphere, however, contains dust particles in the 2-to-10-micrometer range. These dust particles must be removed before the Martian atmospheric gas can be processed. The low pressure of the Martian atmosphere, at 5 to 10 mbars, prevents the development of large voltages required for a standard electrostatic precipitator. If the voltage is increased too much, the corona transitions into a glow/streamer discharge unsuitable for the operation of a precipitator. If the voltage is not large enough, the dust particles are not sufficiently charged and the field is not strong enough to drive the particles to the collector.

A method using electrostatic fields has been developed to collect dust from gaseous environments at low pressures, specifically carbon dioxide at pressures around 5 to 10 mbars. This method, commonly known as electrostatic precipitation, is a mature technology in air at one atmosphere. In this case, the high voltages required for the method to work can easily be achieved. However, in carbon dioxide at low pressures, such as those found on Mars, large voltages are not possible.

The innovation reported here consists of two concentric cylindrical electrodes set at specific potential difference that generate an electric field that produces a corona capable of imparting an electrostatic charge to the incoming dust particles. The strength of the field is carefully balanced so as to produce a stable charging corona at 5 to 10 mbars, and is also capable of imparting a force to the particles that drives them to the collecting electrode.

There are only two possible ways that dust can be removed from Martian atmospheric gas intakes: with this electrostatic precipitator design, and with the use of filters. However, filters require upstream compression of the gas to be treated because the atmospheric pressure on Mars is too close to vacuum to use a vacuum pump downstream to the filter to draw the gas through the filter. The electrostatic precipitator is the best and more efficient solution for this environment. No other precipitator designs have been developed for the environment of Mars due to the challenges of the low atmospheric pressure.

Dust particles are charged using corona generation around the high-voltage discharge electrode, which ionizes gas molecules. Since the atmospheric gas intakes for the ISRU processing chambers will likely be cylindrical, cylindrical precipitator geometry was chosen. The electrostatic precipitator design presented here removes simulated Martian dust particles in the required range in a simulated Martian atmospheric environment. The current-voltage (I-V) characteristic curves taken for the nine precipitator configurations at 9 mbars of pressure showed that a cylindrical collecting electrode 7.0 cm in diameter with a concentric positive high-voltage electrode 100 µm thick provides the best range of voltage and charging corona current. This precipitator design is effective for the size of the dust particles expected in the Martian atmosphere. Mass determination, as well as microscopic images and particle size distributions of dust collected on a silicon wafer placed directly below the precipitator with the field on and off, showed excellent initial results.

This work was done by Carlos Calle of Kennedy Space Center, and Sid Clements of the Appalachian State University Department of Physics and Astronomy. Further information is contained in a TSP (see page 1). **KSC-13657**

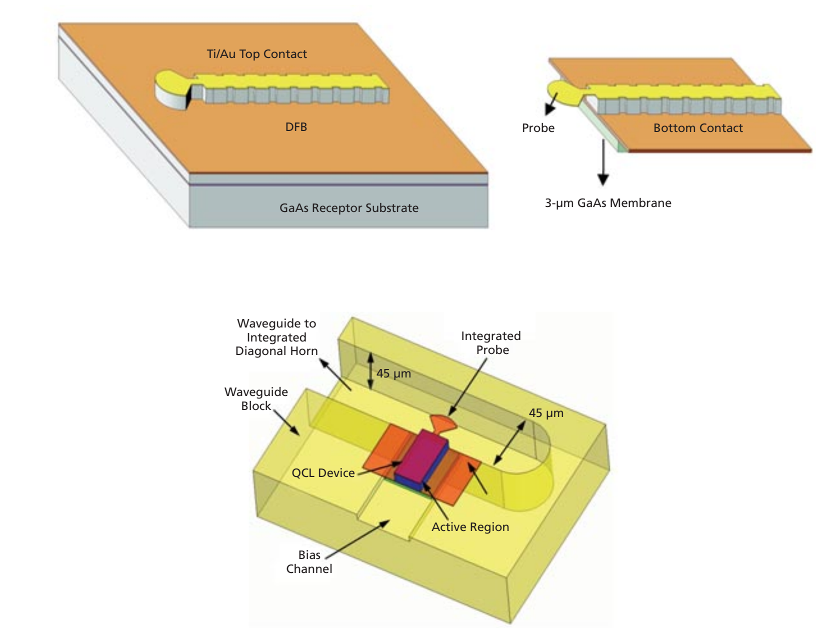
Terahertz Quantum Cascade Laser With Efficient Coupling and Beam Profile

High-power QCLs can be used in medical instruments, security screening equipment, and illicit material detection.

NASA's Jet Propulsion Laboratory, Pasadena, California

Quantum cascade lasers (QCLs) are unipolar semiconductor lasers, where the wavelength of emitted radiation is determined by the engineering of quantum states within the conduction band in coupled multiple-quantum-well heterostructures to have the desired energy separation. The recent development of terahertz QCLs has provided a new generation of solid-state sources for radiation in the terahertz frequency range. Terahertz QCLs have been demonstrated from 0.84 to 5.0 THz both in pulsed mode and continuous wave mode (CW mode).

A 2.7-THz QCL structure uses a metal-metal waveguide QCL with multiple-quantum-well cascade medium to provide terahertz gain for subbands engineered to have the desired energy separation. The approach employs a resonant-phonon depopulation concept. The metal-metal (MM) waveguide fabrication is performed using Cu-Cu thermo-compression bonding to bond the GaAs/AlGaAs epitaxial layer to a GaAs receptor wafer. A laterally corrugated distributed feedback (DFB) grating is etched into a MM waveguide, as



MM-Waveguide QCL Laser shown in (top) a processing schematic for fabrication of the laser with integrated waveguide probe; and (bottom) in a waveguide mount with the integrated radial probe. The top half of the block is removed to show the QCL device inside the waveguide.